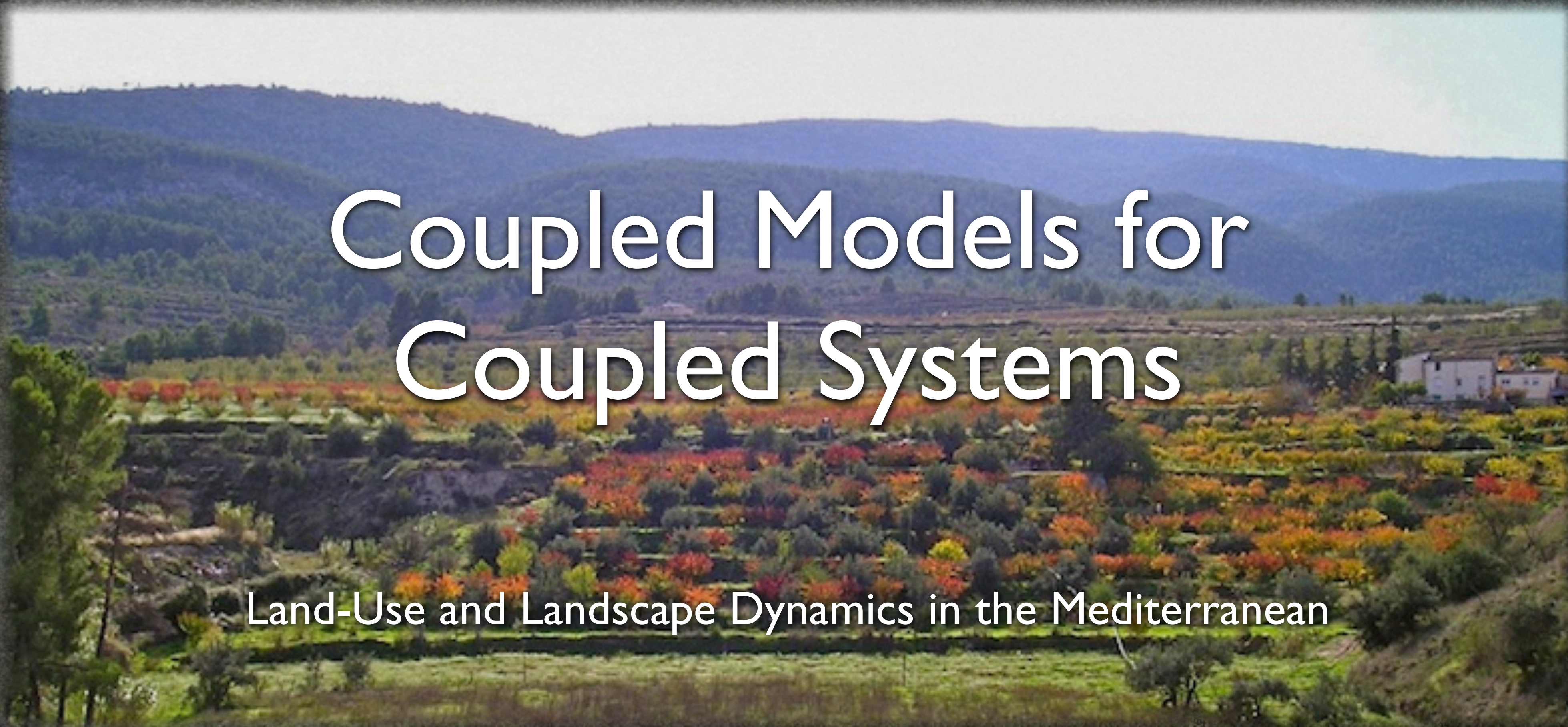

Coupled Models for Coupled Systems

Land-Use and Landscape Dynamics in the Mediterranean

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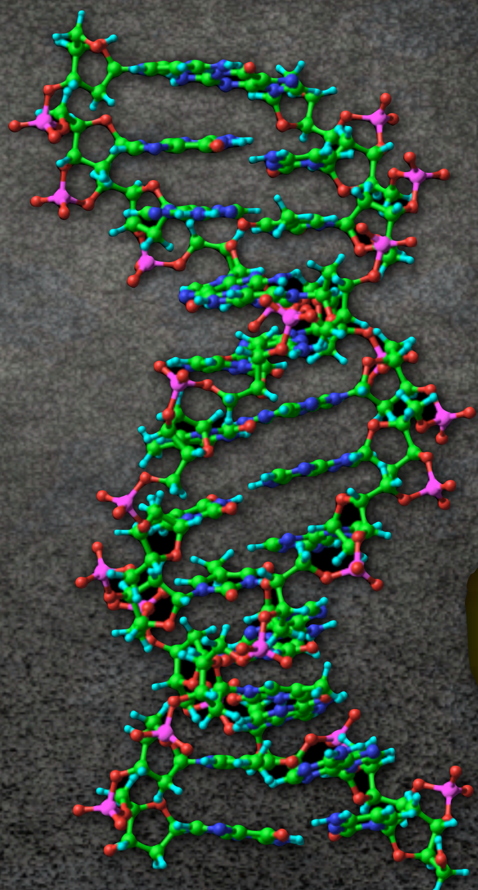
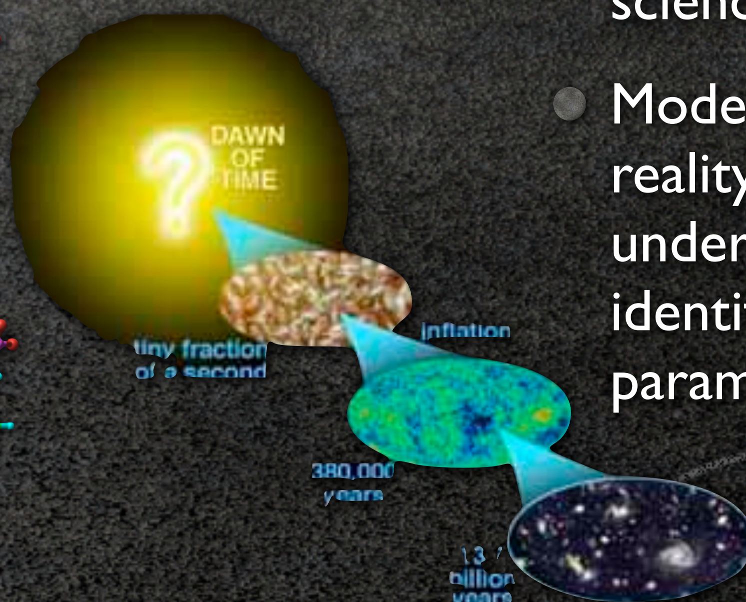
Isaac Ullah (ASU), Gary Mayer (S. Illinois Univ.), Hessam Sarjoughian (ASU), Sean Bergin (ASU), Alexandra Miller (ASU), & Helena Mitasova (N. Carolina State Univ.)

Models for CHANS Science





- A model is an abstract representation of real-world phenomena
- Models are pervasive in science
- Models simplify complex reality to make it understandable, and identify key processes and parameters

Models for CHANS Science

- Models important for CHANS research
  - To understand complex interactions of temporal and spatial dynamics
  - To unravel non-linear causation in highly coupled human and natural systems

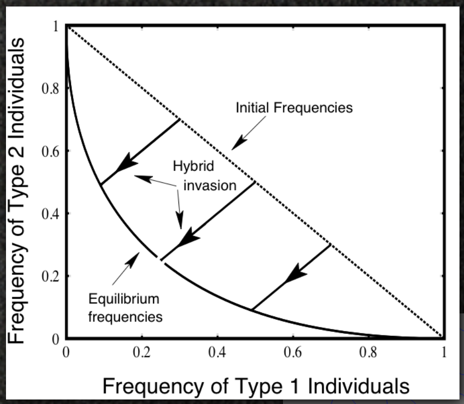
Models for CHANS Science

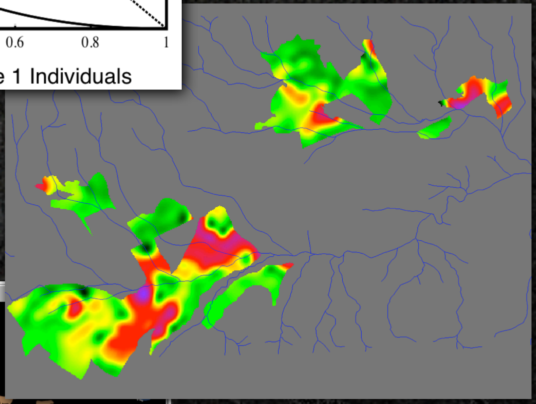
- Natural systems are complex
- Social systems are complex
- But are complex in different ways

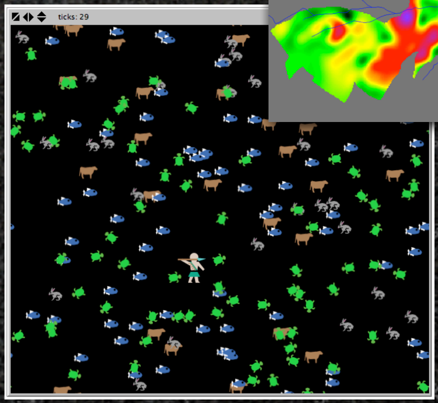



Models for CHANS Science

- Multiple modeling approach, each with different strengths and weaknesses
  - Mathematical models: simple and robust representation of continuous processes; forecasting trends in aggregate phenomena
  - GIS: efficient processing of large, gridded data sets; matrix algebra (map algebra); cellular autonoma (e.g., hydrology)
  - Agent-based modeling: multiple entities that move and interact independently; behavior based on decision rules; interactions among independent agents







Models for CHANS Science

- Coupled social and natural systems compound complexity and dynamics to be modeled
- No single modeling approach adequate to represent all diverse phenomena of complex CHANS

Mediterranean Landscape Dynamics

- Coupling different model formalisms to create a computational laboratory for studying the long-term interactions of agropastoral land-use and landscape change in Mediterranean socioecological systems.
- Modeling environment as experimental laboratory
- Archaeological record of early farming provides data for validating and improving model outcomes.

Study areas in eastern Spain and western Jordan

National Science Foundation BCS-410269

Coupled Natural & Human Systems

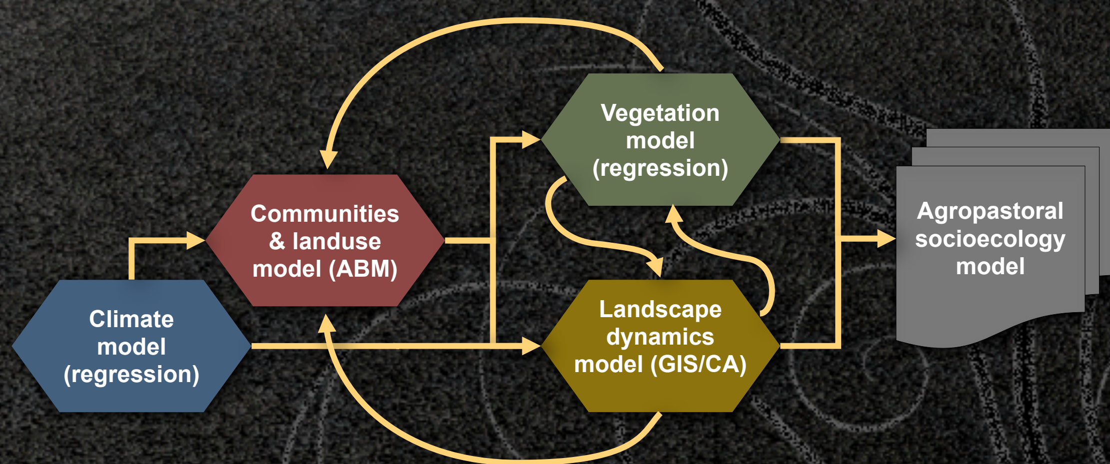
MedLand Modeling Laboratory

- Major components of hybrid modeling laboratory include...
    - ABM of human households and their land-use decisions
    - GIS-based cellular automata of terrain and its changes
    - Regression-based model of local climate
    - Interactive visualization system
- Open source software for research transparency and global accessibility

DEVS Suite (http://www.acims.arizona.edu/SOFTWARE/software.shtml)

GRASS GIS (http://grass.osgeo.org)

World Wind (http://worldwind.arc.nasa.gov/java/)



MedLand Modeling Laboratory

- Overview of some of the components of coupled modeling laboratory
  - Modeling landscape dynamics
  - Modeling paleoclimate dynamics
  - Modeling human decisions
- Initial results of experiments with CHANS associated with beginning of agriculture
  - Interactions of population and land-use practices
  - Effects on landscapes of northwestern Jordan

Modeling Landscape Dynamics

- Hillslope erosion/deposition (HED) model
  - Extension of USPED and RUSLE

$$HED = \frac{\partial T \cdot \cos(\alpha)}{\partial x} + \frac{\partial T \cdot \sin(\alpha)}{\partial y}$$

- HED ➡ net erosion/deposition per landscape cell
- a = topographic aspect [flow direction]

$$T = R \cdot K \cdot C \cdot A^m \cdot \sin(B)^n$$

[modified RUSLE for hillslopes]

- Where...
  - R = rainfall coefficient
  - K = soil erodibility coefficient
  - C = landcover coefficient
  - A = upslope area contributing to flow
  - m,n = empirical coefficients for different flow regimes
  - B = slope

Modeling Landscape Dynamics

- Change from sediment-limited to transport-limited process equation for streams
  - Same HED equation, but T changes to include shear stress of flowing water

$$HED = \frac{\partial T \cdot \cos(\alpha)}{\partial x} + \frac{\partial T \cdot \sin(\alpha)}{\partial y}$$

$$T = K_t |\tau|^n$$

- Where

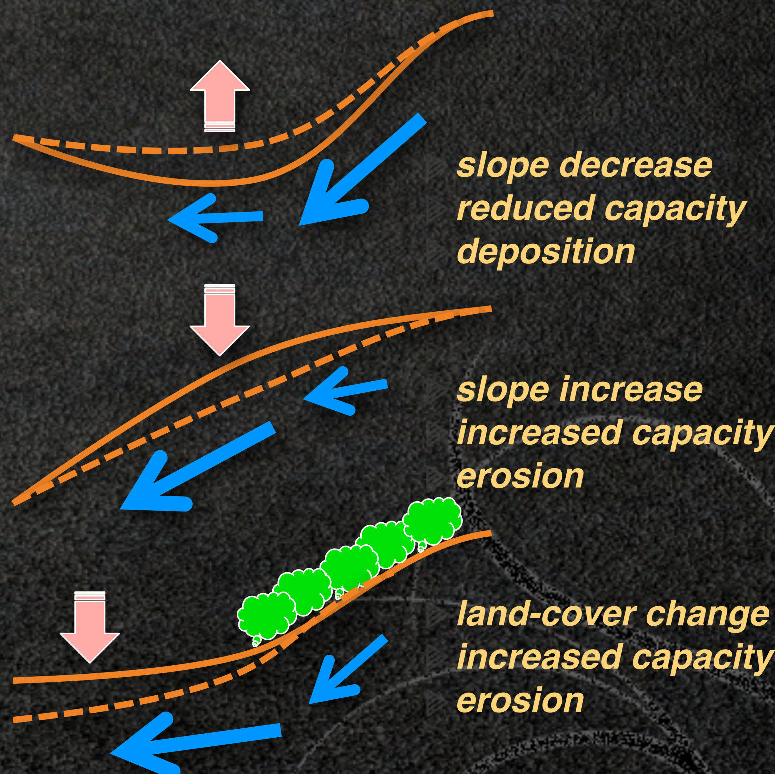
$$\tau = 9806.65 \cdot B \cdot D$$

$$D = \frac{(R_m - (R_m \cdot i)) \cdot A}{R_d \cdot 1440}$$

- 9806.65 is a constant related to the gravitational acceleration of water
- and R, K, A, m, n, and B are the same as for hillslopes

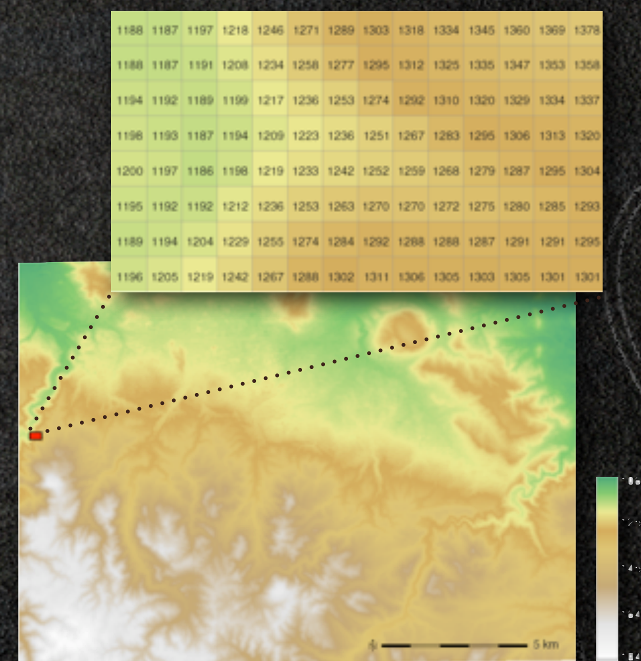
Modeling Landscape Dynamics

- Potential sediment flux - sediment-limited process equations
- Basic assumption
  - flowing water carries sediment at capacity
- Dynamics
  - Changes to hydrology affect transport capacity
  - Water will erode or deposit sediment until its load reaches its new capacity



Modeling Landscape Dynamics

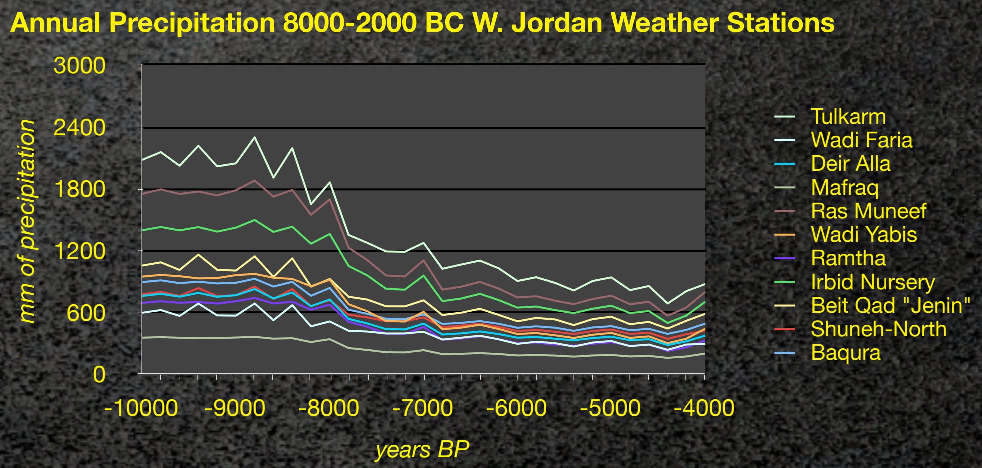
- Implemented as recursive scripts in open source GRASS GIS
  - Start with DEM of topography
  - Calculate HED (net erosion/deposition) for each landscape cell
  - Add/subtract net erosion/deposition to DEM
  - Create new DEM of topography



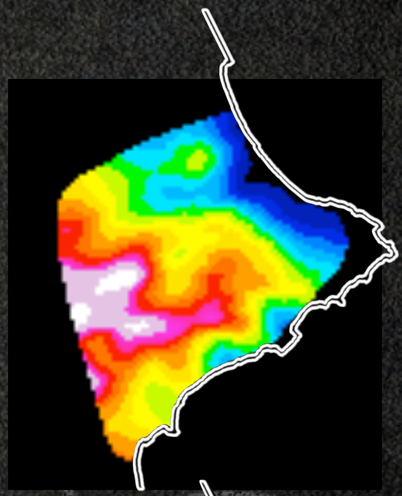
1188	1187	1197	1218	1246	1271	1289	1303	1318	1334	1345	1360	1369	1378
1188	1187	1191	1208	1234	1258	1277	1295	1312	1325	1335	1347	1353	1358
1194	1192	1189	1199	1217	1236	1253	1274	1292	1310	1320	1329	1334	1337
1198	1193	1187	1194	1209	1223	1236	1251	1267	1283	1295	1306	1313	1320
1200	1197	1186	1198	1219	1233	1242	1252	1259	1268	1279	1287	1295	1304
1195	1192	1192	1212	1236	1253	1263	1270	1270	1272	1275	1280	1285	1293
1189	1194	1204	1229	1255	1274	1284	1292	1288	1288	1287	1291	1291	1295
1196	1205	1219	1242	1267	1288	1302	1311	1306	1305	1303	1305	1301	1301

Modeling Climate Dynamics

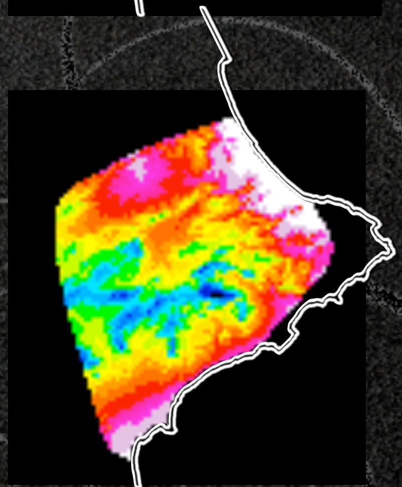
- Point climate models calculated at weather stations
- Transformed into paleoclimate landscapes using multiple regression
- Regression coefficients applied to DEMs to generate climate surfaces



Annual precipitation



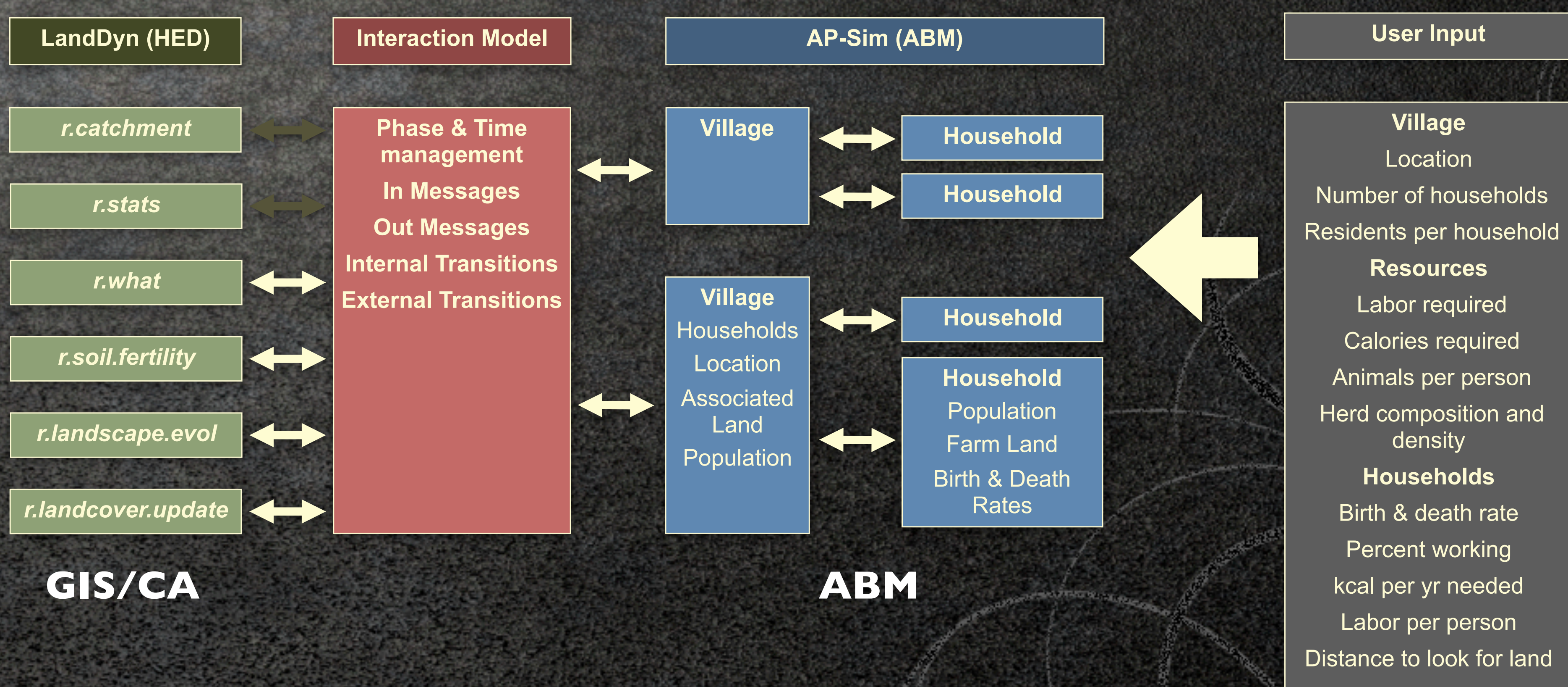
Annual temperature



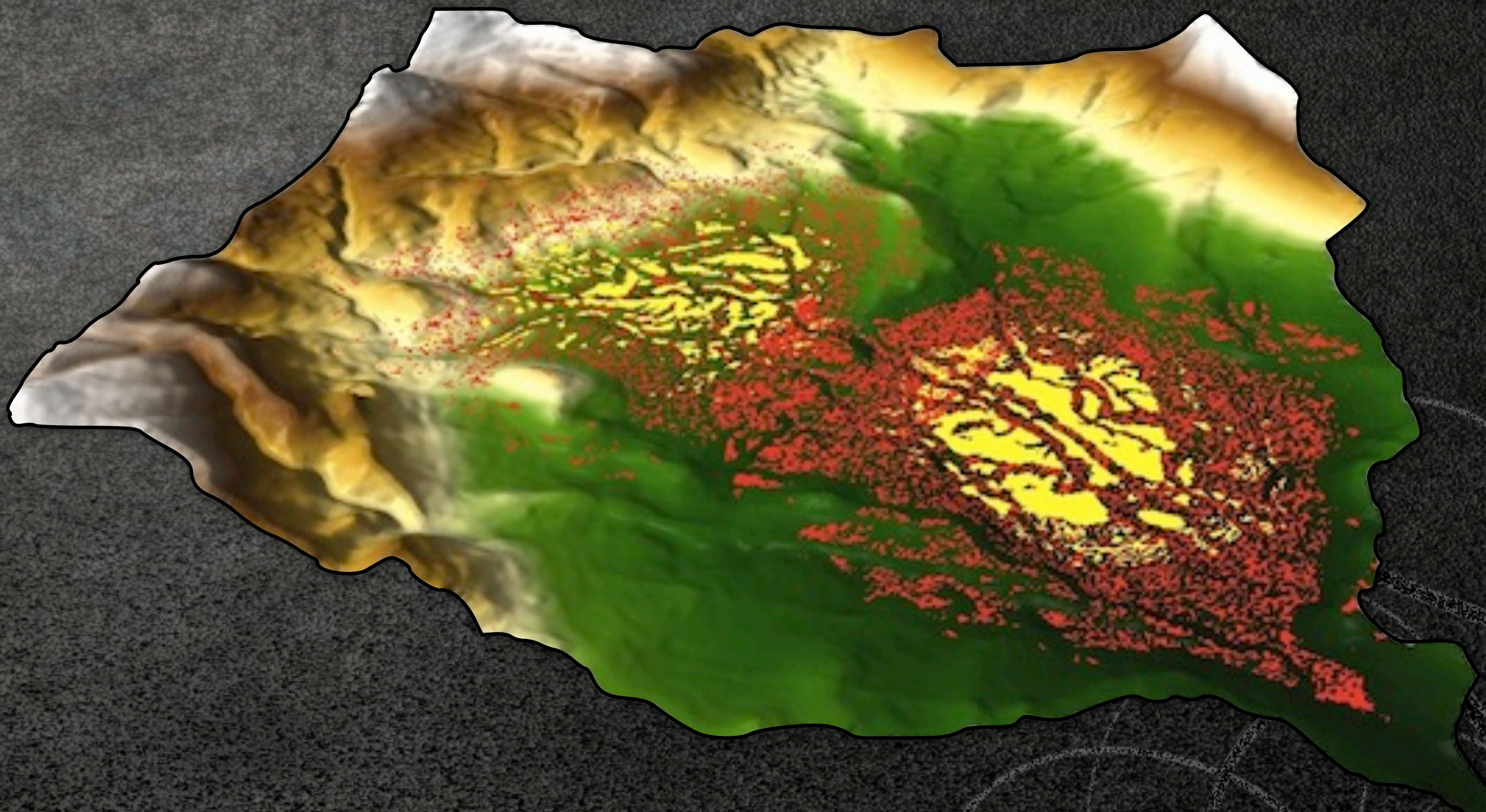
Paleoclimate, E.Spain 10,000-3,000 BP

Modeling Land-Use

- Coupled model



Land-use/Landscape Dynamics in Mediterranean Spain



Coupled model output (yr 5): cultivation and grazing on early Holocene landscape, Penaguila Valley, Alicante Province, Spain.

Visualizing Coupled Models

- Visualization using open source WorldWind (NASA)

Experiments in Long-Term Socioecology

- **Results of initial experiments (40 & 200 year simulations) in northwestern Jordan**
- Barton, C. M., Ullah, I., & Mitasova, H. (2010) Computational modeling and socioecological dynamics: a case study from southwest Asia. *American Antiquity.*
- Barton, C.M. (n.d.) Land-use, water, and Mediterranean landscapes: modeling long-term dynamics of socioecological systems. *Phil.Trans. B Royal Society* (in review).

Experiments in Long-Term Socioecology

- Experimental design

Settlement	Precip. & Soil	Agropastoral Land-Use Experiments	
Small village with 5-20 families. Like Tell Rakkan ca. 8400 cal BP (PPNB)	918.5 mm/yr R-factor = 6.69 K-factor = 0.42	No cultivation	No grazing
		Intensive cultivation	No grazing
			Grazing
		Shifting cultivation	No grazing
			Grazing
Hamlet with 1-5 families. Like Tabaqat al-Bûma ca. 7400 cal BP (PN)	783.7 mm/yr R-factor = 5.26 K-factor = 0.42	No cultivation	No grazing
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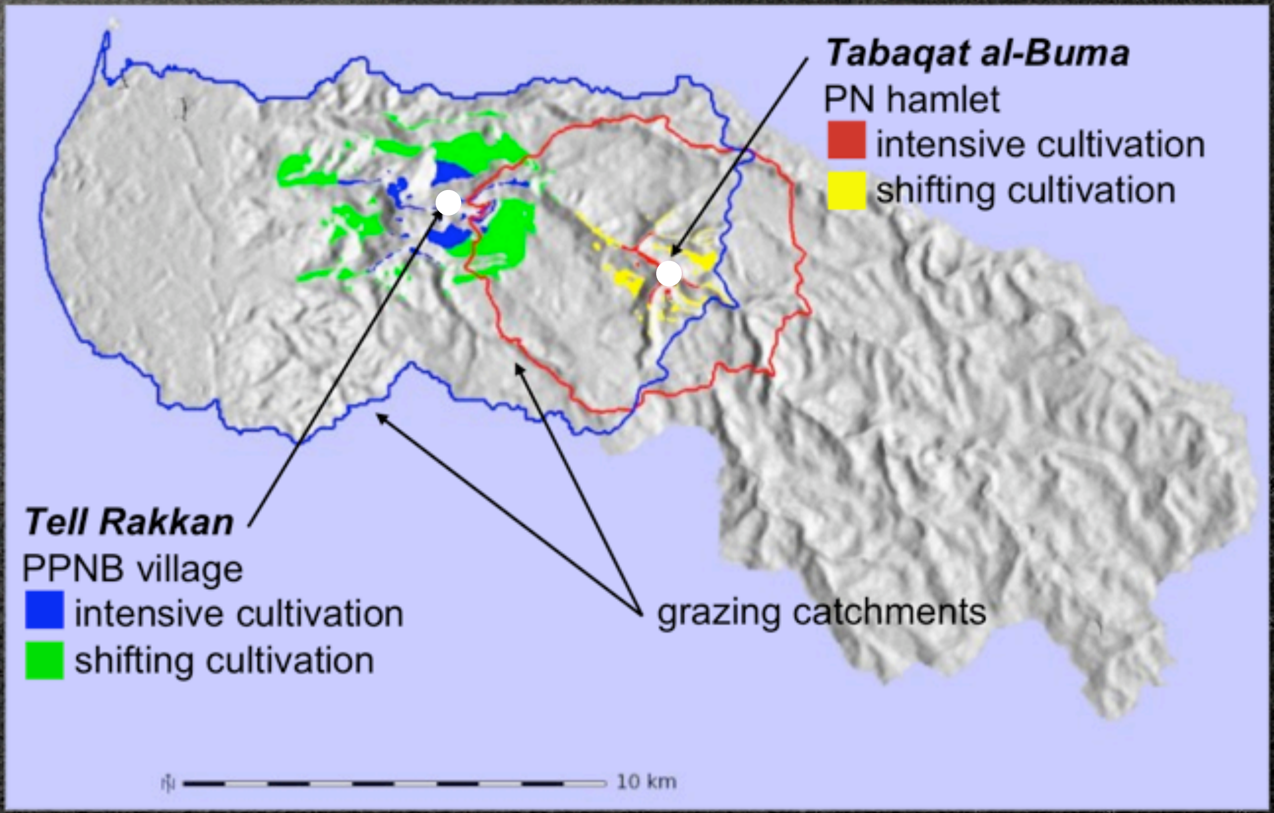
			Grazing

Experiments in Long-Term Socioecology

- Land-use modeling



Experiments in Long-Term Socioecology

- Control model

Settlement	Precip. & Soil	Agropastoral Land-Use Experiments	
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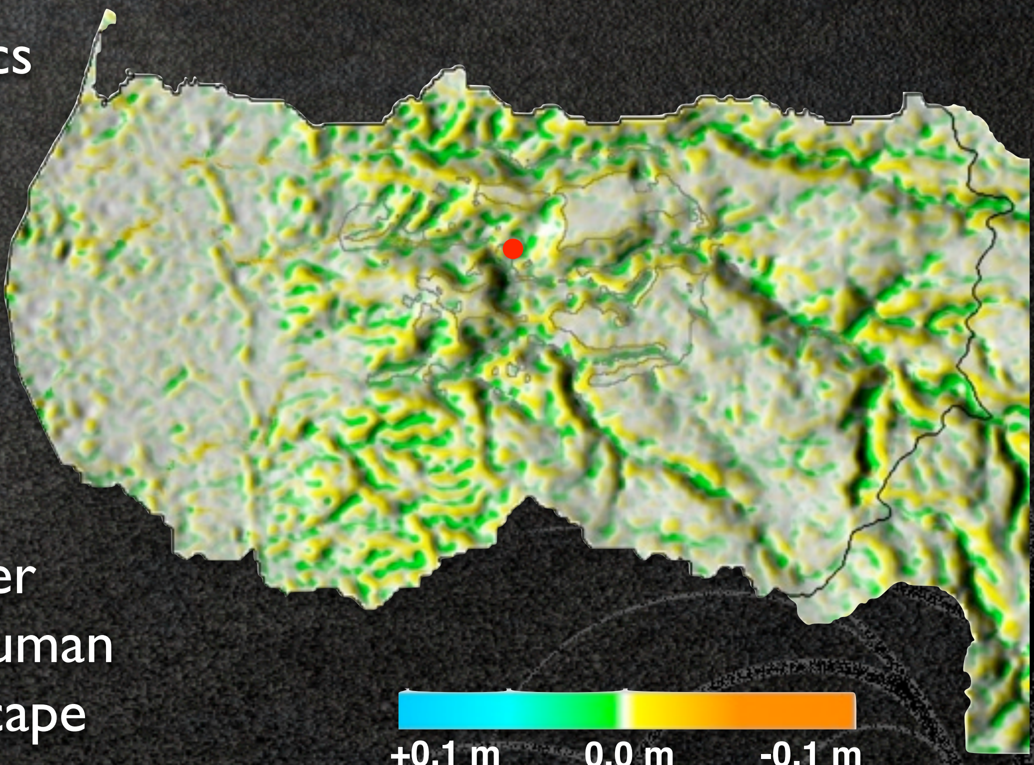
Experiments in Long-Term Socioecology

- Control model after 40 years. Landscape dynamics without people
  - Contrafactual paleoecology
  - Only possible with modeling
  - Used to calibrate other results to show net human contribution to landscape change



Experiments in Long-Term Socioecology

- Small village, shifting cultivation, grazing

Settlement	Precip. & Soil	Agropastoral Land-Use Experiments	
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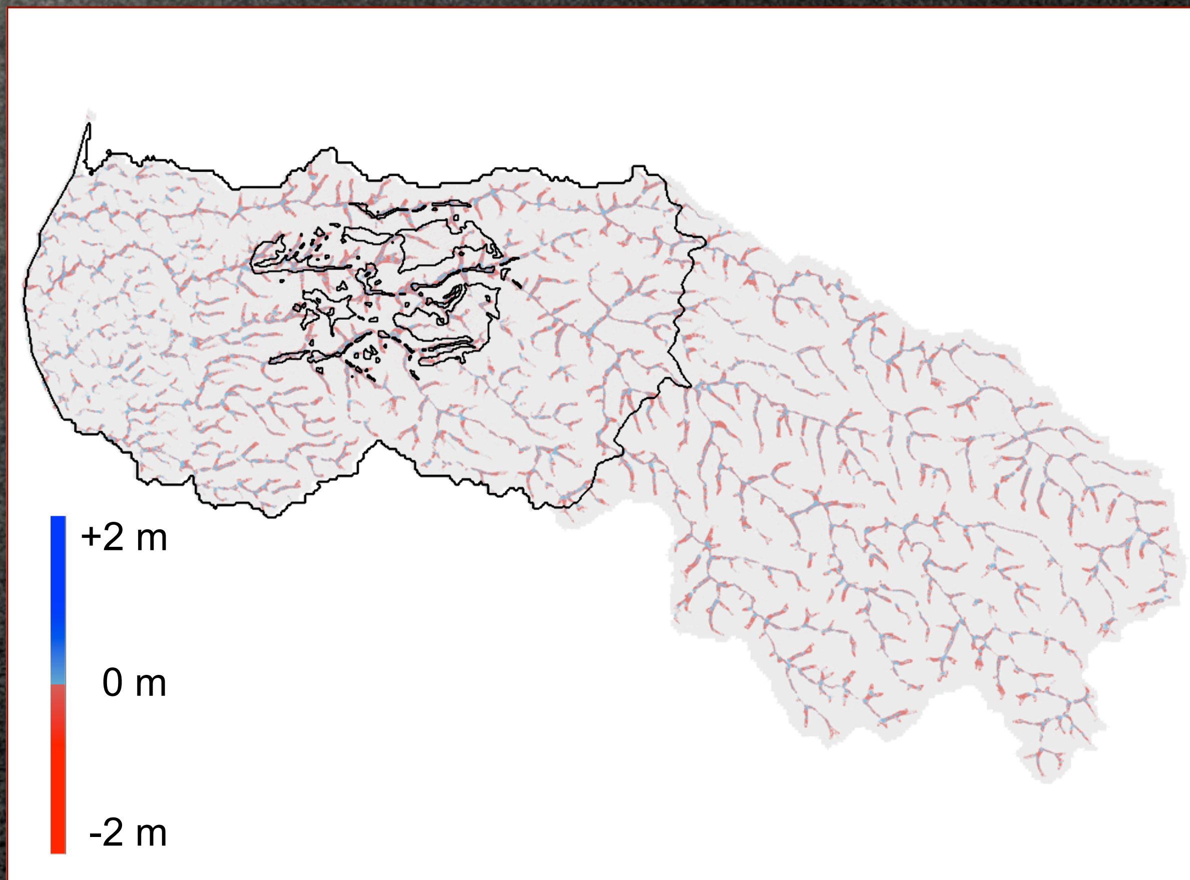
Experiments in Long-Term Socioecology

- Small village, shifting cultivation, grazing (40 years)



Experiments in Long-Term Socioecology

- Comparing consequences of population change

Settlement	Precip. & Soil	Agropastoral Land-Use Experiments	
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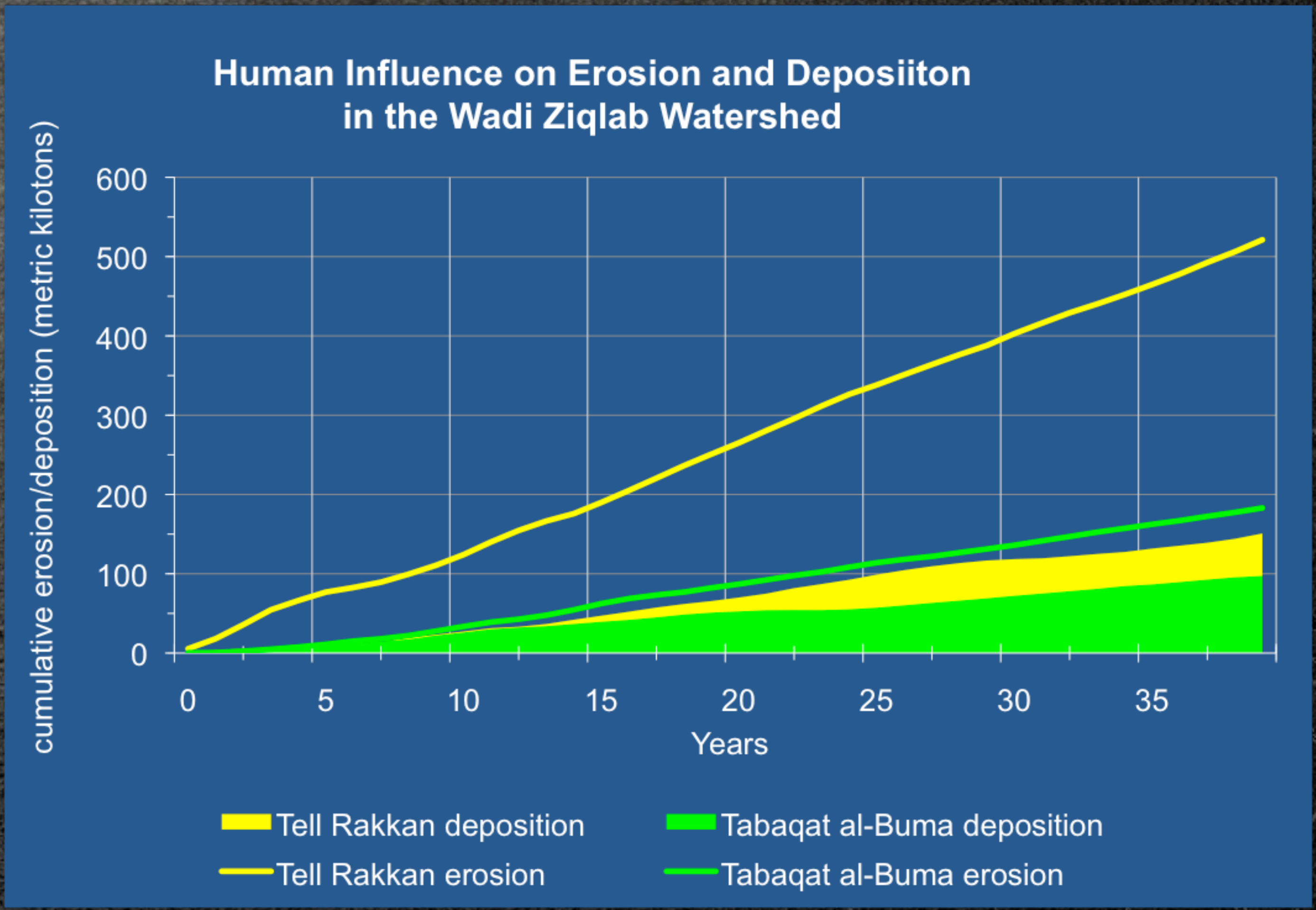
Experiments in Long-Term Socioecology

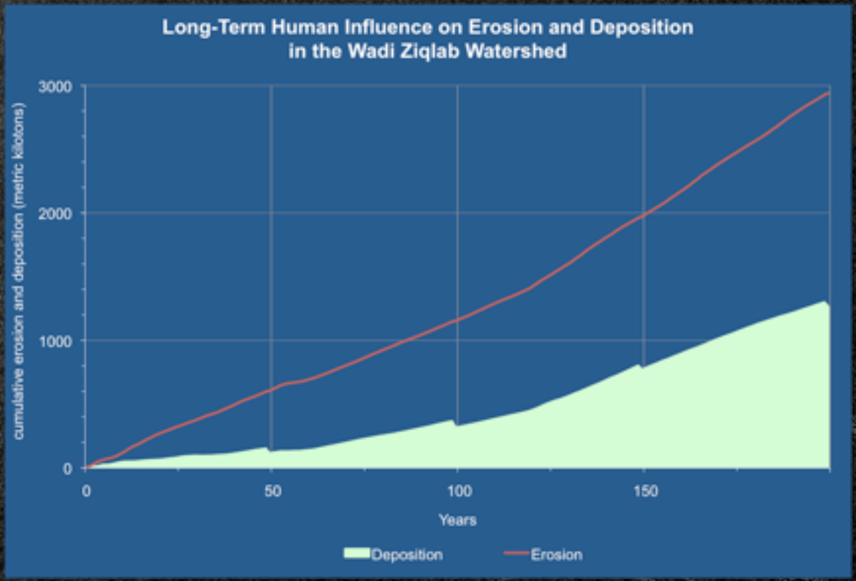


Experiments in Long-Term Socioecology

- Hamlet
  - Cultivation limited to wadi bottoms
  - Grazing causes most erosion
  - Erosion primarily in uncultivated uplands
  - Redeposited sediment in cultivated zones is 53% of erosion
- Village
  - Cultivation in uplands; more extensive grazing
  - Cultivation causes most erosion
  - Erosion in cultivated and uncultivated zones
  - Redeposited sediment only 29% of erosion

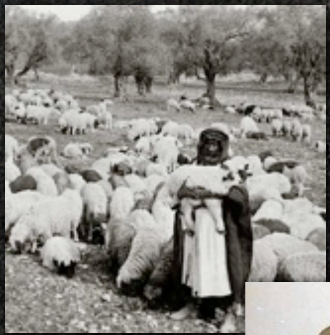
Experiments in Long-Term Socioecology

- Long-term outcomes
- 200 years of land-use around village
  - Erosion continues for 200 years
  - Rate of erosion increases
  - Erosion continues to outpace deposition



Experiments in Long-Term Socioecology

- Comparisons with the archaeological record
- Growth of Neolithic communities through the Pre-Pottery Neolithic
- Villages to larger "megasites" by end of Pre-Pottery Neolithic B
- Subsequent disappearance of large communities
  - Prevalence of smaller communities
  - Initial appearance of pastoralism
  - Initial appearance of significant socioeconomic differentials

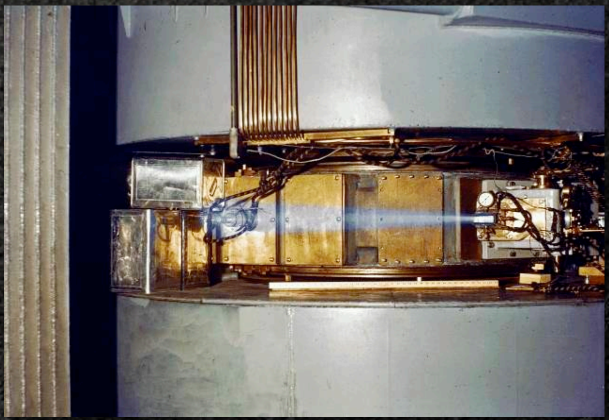


Computational Modeling & Social Science

- Without computational modeling...
  - Long-term consequences of decisions and environemental not easily visible in CHANS
  - Difficult to trace causation or forecast consequences due to complex interactions and feedbacks(couplings)
- Complex causality shown here would not have been apparent to farmers 'on the ground' trying to understand declining productivity

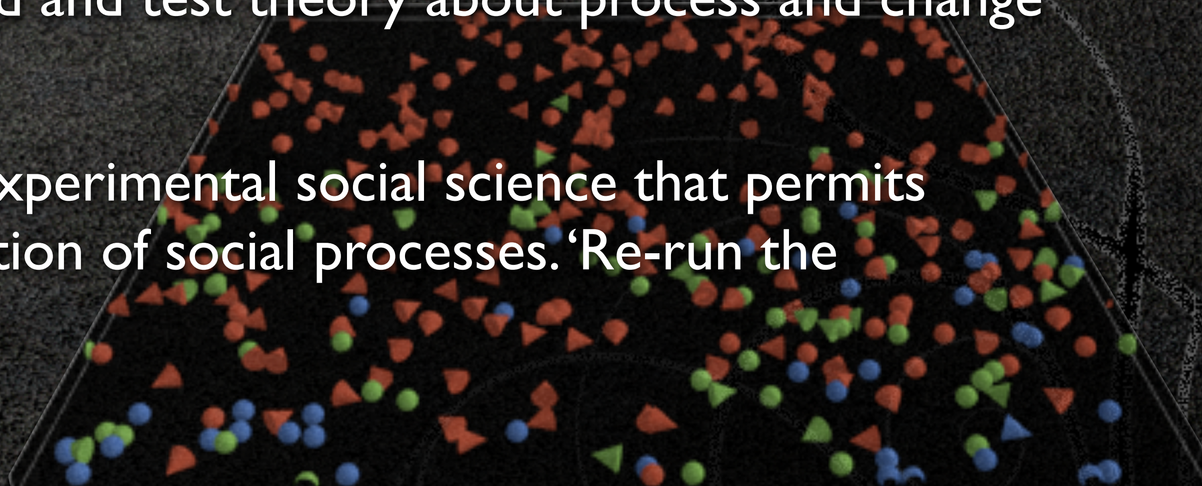
Computational Modeling & Archaeology

- Science is not technology, but technology is an important component of mature sciences
- Some technologies can even be transformative for science
- Telescope
- Microscope
- Cyclotron



Computational Modeling & Social Science

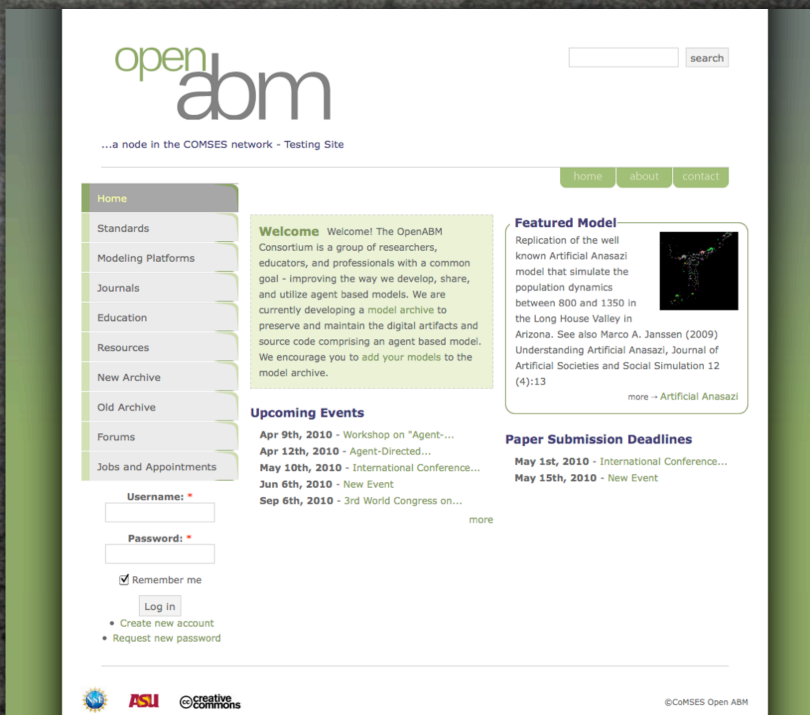
- Computational modeling a potentially transformative technology in science of coupled human and natural systems
- Allows us to express complex interactions and dynamics in quantitative form that can be better communicated across scientific disciplines, and independently evaluated
- Transparently build and test theory about process and change in social systems
- Create a robust experimental social science that permits controlled replication of social processes. 'Re-run the tape' (S.J. Gould)



Computational Modeling & Social Science

- BUT requires…
  - "Computational thinking" about social-natural dynamics (models vs. simulations)
  - Familiarity with computer-based tools
  - Investment of time for 'intellectual retooling'
  - Investment of institutional human resources
- CHANS scientists need to be involved with the development of these important tools for our research
- Need to train our students (and ourselves) in the use of new research methods
- Need to share knowledge of this new technology to jump-start a science of social dynamics.

Computational Modeling for SES
CoMSES Network



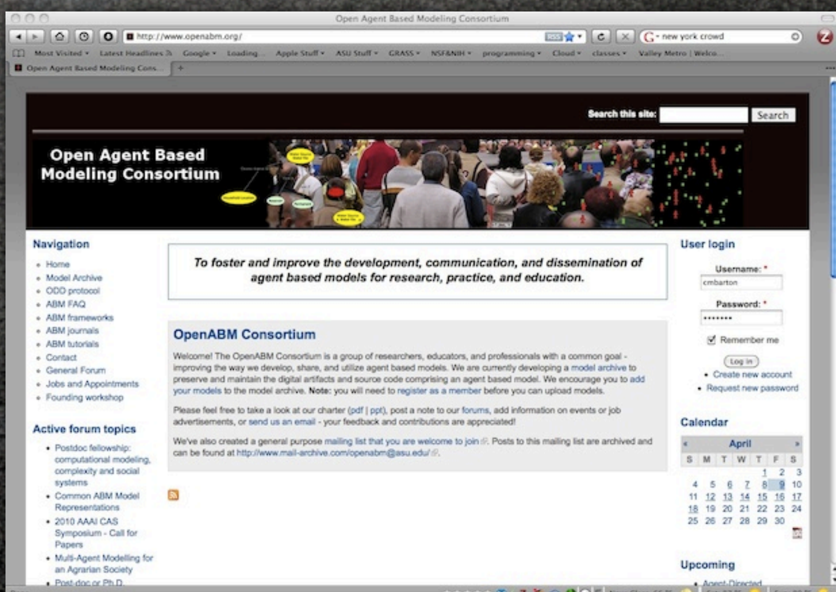
- New community of practice for researchers in social and ecological sciences
- Improving access to computational tools for complex systems modeling
- Sharing experiences and strategies
- Promoting a science of social dynamics

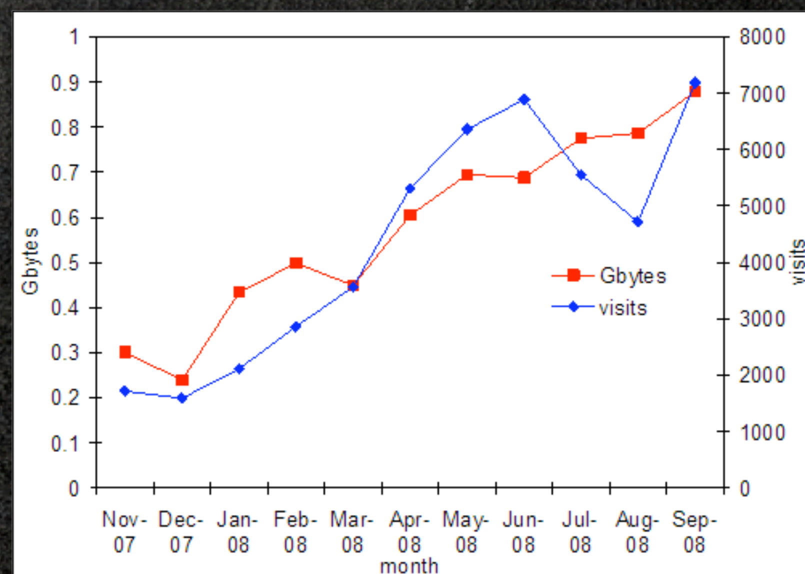
OpenABM

- Recognition of the importance of computational modeling to the future of CNH science
- But widespread lack of expertise in or access to computational modeling by CNH scientists
- Pilot project and workshop to...
  - ID reasons for lack of use of and access to computational modeling
  - Initiate a community of practice to mitigate these issues

OpenABM

- Launched as Open Agent-Based Modeling Consortium in 2007
- Web based resource center (http://www.openabm.org)
- Highly successful





CoMSES Network

- Launched February 2010 with planning workshop to address barriers to use of computational modeling in normal science practice
  - Standards
  - Logistics of dissemination
  - Evaluation of research
  - University curricula
- Creating an international network for...
  - Promoting standards and best practices
  - Knowledge scaffolding. New ways to continue the practices that have made science successful.

CoMSES Network

- New internet site
  - NSF SES models library to be seeded with CNH projects (**We want your models!**)
  - Educational materials library
  - Cyberinfrastructure for scientific networking and information sharing
- Online journal
- Get involved: *http://www.openabm.org*

Interdisciplinary & International Collaboration

- ASU: School of Human Evolution and Social Change, Center for Social Dynamics & Complexity, School of Earth and Space Exploration, School of Computing Informatics and Decision Systems Engineering, School of Geographical Sciences and Urban Planning, School of Sustainability
- Partners: Universitat de València, Universidad de Murcia, University of Jordan, North Carolina State University, University of Wisconsin, Hendrix College, Geoarchaeological Research Associates, GRASS GIS Development Team